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Short communication

Influence of gait speed on free vertical moment during walking

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ABSTRACT

Free vertical moment (FVM) of ground reaction is recognized to be a meaningful indicator of torsional stress on the lower limbs when walking. The purpose of this study was to examine whether and how gait speed influences the FVM when walking. Fourteen young healthy adults performed a series of overground walking trials at three different speeds: low, preferred and fast. FVM was measured during the stance phase of the dominant leg using a force platform embedded in a 10 m-long walkway. Transverse plane kinematic parameters of the foot and pelvis were measured using a motion capture system. Results showed a significant decrease in peak abduction FVM (i.e., resisting internal foot rotation) and an increase in peak adduction FVM (i.e., resisting external foot rotation), together with an increase in gait speed. Concomitantly, we observed a decrease in the foot progression angle and an increase in the peak pelvis rotation velocity in the transverse plane with an increase in gait speed. A significant positive correlation was found between the pelvis rotation velocity and the peak adduction moment, suggesting that pelvis rotation influences the magnitude of adduction FVM. Furthermore, we also found significant correlations between the peak adduction FVM and both the step length and frequency, indicating that the alterations in FVM may be ascribed to changes in these two key variables of gait speed. These speed-related changes in FVM should be considered when this parameter is used in gait assessment, particularly when used as an index for rehabilitation and injury prevention.

1. Introduction

Analysis of ground reaction forces (GRF) is a classical approach for assessing gait in both the research and clinical fields. Indeed, GRF, which are usually measured by walking on a force platform, can be used to quantify the deviation of gait from normal and thus identify walking impairments (Andriacchi et al., 1977; Claeys, 1983). Such information is used, for instance, by physicians to select surgical or other therapeutic interventions for gait improvement and perform post-intervention follow-up procedures (Marasovic et al., 2009).

The role of GRF in gait has been extensively studied in the literature. The patterns formed by the three components of GRF (i.e., anteroposterior, mediolateral and vertical) and their changes with gait speed are also well known (e.g., Andriacchi et al., 1977; Nilsson and Thorstensson, 1989). However, much less attention has been paid to the free vertical moment (FVM) of ground reaction, which represents the torque that acts about the vertical axis that originates at the foot's centre of pressure (CoP) and results from shear forces between the foot and the ground (Holden and Cavanagh, 1991). Nonetheless, evidence suggests that FVM may be indicative of the torsional stress exerted on the lower limbs (Ohkawa et al., 2017; Yang et al., 2014), and that this parameter may provide useful clinical information for injury prevention (Hasan et al., 1991) and rehabilitation (Stan and Orban, 2014).

It is generally recognized that FVM exhibits a biphasic shape during the stance phase of walking (Almosnino et al., 2009; Farahpour et al., 2016). This is characterized by an initial abduction moment (i.e., resisting the foot's internal rotation) followed by an adduction moment (i.e., resisting external rotation) whose peak magnitude has been related to the torsion of the lower extremity (Ohkawa et al., 2017; Yang et al., 2014). However, to date little is known about the influence of gait speed on FVM. Indeed, although a study has shown that FVM pattern may change in conditions of fast walking (Li et al., 2001), it still remains to determine whether and how the magnitudes of the abduction and adduction peaks of FVM are influenced by gait speed. Such knowledge is important because these FVM parameters are used in clinical gait assessment (Hasan et al., 1991; Stan and Orban, 2014). The aim of this study was therefore to examine the influence of gait speed on the FVM when walking.

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2. Methods

2.1. Subjects

Fourteen healthy subjects (7 males and 7 females; age: 22.5 ± 2.4 years, height: 171 ± 10 cm, body mass: 65.9 ± 7.9 kg) participated in this experiment. All gave written consent after being fully informed of the test procedure, which was approved by the local ethics committee.

2.2. Experimental set-up and protocol

Subjects were instructed to walk barefoot along a 10-m walkway, in the middle of which was embedded a force-plate (60 × 40cm, AMTI). This force-plate measured GRF and moments. Retro-reflective spherical markers (14-mm diameter) were fixed bilaterally on bony landmarks according to the Vicon's Plug-in-Gait lower-body model (Kadaba et al., 1990): anterior and posterior superior iliac spines, thigh, knee, tibia, ankle, heel and second metatarsophalangeal head. A motion capture system equipped with six cameras (Bonita, Vicon) was used to collect simultaneously the kinematic data at 200 Hz and force-plate data at 1000 Hz.

Subjects were asked to perform walking trials in Slow, Preferred and Fast conditions. These speeds corresponded, respectively, to 60%, 100% and 140% of the preferred walking speed, which was determined before the experiment onset by asking subjects to walk at their comfortable speed over a 100-m distance. During the experiment, the walking speed was controlled by two pairs of photoelectric cells, which were placed two meters in front and two meters behind the force-plate. For each speed condition, a trial was considered successful only if the walking speed was within ±2.5% of the target velocity and the entire foot of the subject's dominant leg (the preferred limb used for kicking a ball) landed on the force-plate. This procedure was repeated until three successful trials were obtained. The presentation order of the speed conditions was randomized for all subjects.

2.3. Data analysis

Both the force-plate and kinematic data were low-pass filtered using a fourth-order Butterworth filter with a 10 Hz cut-off frequency. The CoP coordinates were calculated in accordance with the manufacturer's instructions.

The FVM during the stance phase of walking was calculated as follows:

$$FVM = M_Z - (CoP_X \times F_Y) + (CoP_Y \times F_X),$$

where M_Z is the moment acting about the vertical axis at the centre of the force-plate, where CoP_X and CoP_Y are the CoP coordinates along the mediolateral and anteroposterior axes, respectively, and where F_X (positive to the right) and F_Y (positive in the direction of gait) are the GRF along the mediolateral and anteroposterior axes, respectively. By convention, FVM was considered positive in the direction of adduction. To preserve this sign convention, the FVM calculation was negated when the dominant foot was the left side.

The stance phase of the dominant leg was determined from the vertical GRF with a threshold of 10 N.

2.4. Dependant variables

The peak abduction ($PeakABD_{FVM}$) and adduction ($PeakADD_{FVM}$) values of FVM, the time of occurrence of these peaks (as a percentage of the stance duration), the net impulse of each FVM phase (abduction and adduction), the net impulse of FVM during the stance phase (net area under the FVM curve) and the stance phase duration were calculated. To decrease between-subject variability, FVM values were normalized by the product of the subject's body weight and height.

We also calculated various kinematic parameters in the transverse plane that are associated with the torsion of lower limb and recognized as an influence on the magnitude of peak adduction FVM. Foot progression angle (FPA) was calculated as the mean angle between the forward laboratory axis and the long axis of the foot during the foot-flat phase (Simic et al., 2013). The maximal pelvis angle with forward laboratory axis and the maximal relative angle between the stance foot and the pelvis during the stance phase were calculated according to Ohkawa et al. (2017). During the stance phase, the absolute value of the peak pelvis angular velocity towards the stance limb was calculated (Buckley et al., 2010). Pelvis angular velocity about the vertical axis was computed from time-derivatives of the Euler orientation angles projected into the global reference frame (Winter, 1990). Finally, we calculated the step frequency, step length and step width from left and right heel markers during the stance phase (Ijmker et al., 2013).

2.5. Statistical analysis

Each variable was averaged over the three trials per subject. ANOVAs with repeated-measures on speed were conducted

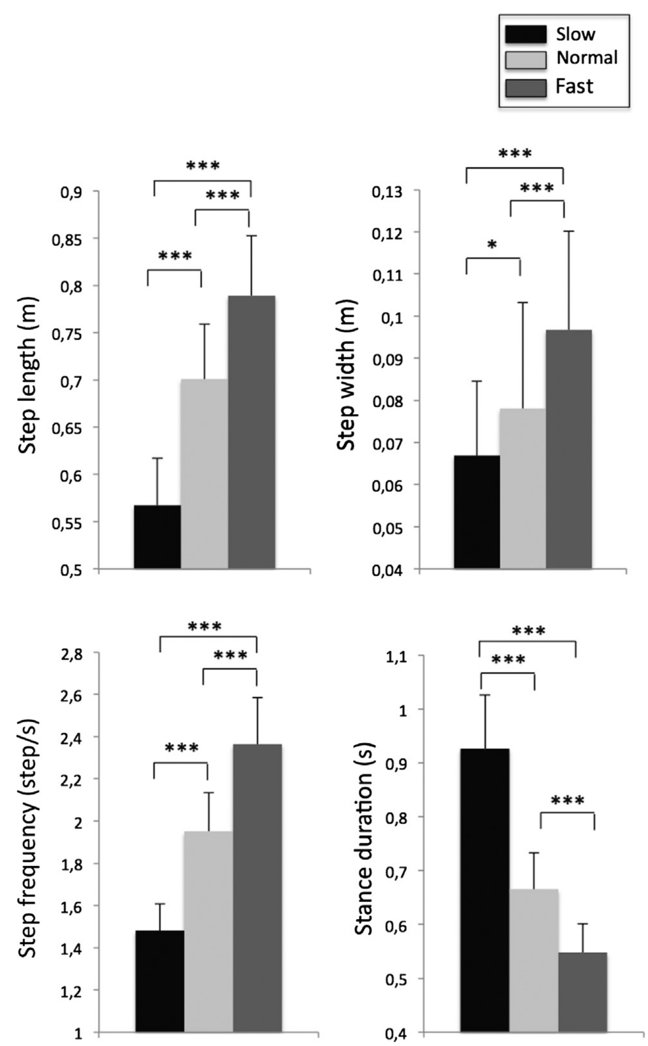

Fig. 1. Mean of spatial-temporal parameters for the slow, preferred and fast speed conditions: step length, step width, step frequency and stance duration. *, ***: significant difference with $p < 0.05$ and $p < 0.001$, respectively.